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Effect of ion irradiation on low-cycle fatigue of pressed profiles of the V95 alloy after artificial aging

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Abstract. The effect of 20–40-keV Ar^+ ion irradiation on the fatigue resistance of hot-pressed V95 alloy (Al–Zn–Mg–Cu system) profiles 6 mm thick after quenching and artificial aging (140°C, 16 h) has been investigated. The use of the irradiation conditions (E = 40 keV, j = 500 μA/cm^2), under which the profiles were briefly heated to a temperature of 200°C, is found to reduce the strength properties of the alloy significantly, which does not meet the specified requirements. Irradiation conditions, which enable one to avoid significant heating of a target at E = 20 keV and j = 400 μA/cm^2, do not affect the fatigue resistance significantly at all fluences of $F = 1\cdot10^{15}$, $1\cdot10^{16}$ and $1\cdot10^{17}$ cm^{-2}.

1. Introduction

Ion implantation of metal materials (in particular, titanium-based steels and alloys) is considered as one of the ways to increase their service life under fatigue conditions [1–7].

Medium-energy ion bombardment melts nanosized metal surface layers [8, 9] (due to the formation of thermal spikes zones 10–20 nm in diameter and heated to 3000–6000 K) during trillionths of a second. However, this melting occurs with time rather than simultaneously, when individual ions are introduced (time required for the formation of a thermal spike is ~10^{-12} s and cooling time, ~10^{-11} s). This effect can result in healing of nano and microcracks. In addition, implanted impurities create compressive stresses near the surface of materials. In view of the aforesaid as well as the long-range dynamic effects of the structure improvement due to the propagation of post-cascade high-power elastic shock waves [8, 9], the mechanical and life properties of the alloys can be expected to increase (due to changes in the structure of both the surface and the volume of irradiated media).

The aim of this work is to investigate the effect of Ar^+ ion irradiation on the fatigue resistance of hot-pressed V95 alloy (Al–Zn–Mg–Cu system) profiles 6 mm thick in the as-delivered state, namely, after quenching and artificial aging (140°C, 16 h).

2. Experimental

Bulk workpieces (30 cm long) cut from the PR100-23 profiles (6 mm thick) were irradiated with continuous Ar^+ ion beams in an ILM-1 ion beam implanter equipped with a PULSAR-1M ion source based on a glow discharge with a hollow cold cathode [10]. A line-focus ion beam was cut from a cylindrical ion beam using a collimator. The flat profile surfaces were irradiated on both sides of the profiles when they were moved under the ion beam at different speeds. The temperature of the samples during irradiation was controlled via a chromel–alumel thermocouple welded to a similar test sample and a computerized digital signal measurement system based on ADAM-4000 modules. Irradiation parameters are listed in table 1.

Table 1. Conditions of irradiation of V95 alloy profiles with continuous Ar^+ ion beams.

No. Mode	Ion energy E, keV	Ion current density j, $\mu A/cm^2$	Collimator width *d*, cm	Target velocity, v, cm/s	Number *n* of passes (from both sides)	Irradiation time* (one-side irradiation) t, s	Ion fluence (one-side irradiation) *F*, cm^{-2}	Maximum temperature of a sample *T*, °C
1	40	500	10	1	3+3	30	$9.4 \cdot 10^{16}$	200
2					5+5	4	$1 \cdot 10^{16}$	40
3	20	400	2	2.5	1+1	0.8	$1 \cdot 10^{15}$	30
4					50+50	40	$1 \cdot 10^{17}$	60

* The total time that each profile surface point is under the beam is indicated.

Further, the irradiated profiles were used to produce standard samples for fatigue testing. Samples were tested on an INSTRON-8801 universal servohydraulic tester equipped with a computer and a FastTrack controller. All operations during the experiment are made by software and hardware. Sinusoidal cycle fatigue tests are performed at a loading frequency of 3 Hz to determine the Weller fatigue curve. The asymmetry coefficient of the cycle is -1.

3. Details of exposure, measurements and results

Figure 1 presents Weller's curves built using the tests on the initial and irradiated samples in modes 1–4. The use of the irradiation mode 1 (E = 40 keV, j = 500 $\mu A/cm^2$), under which the profiles were briefly heated to a temperature of 200°C, is found to reduce the strength properties of the alloy significantly, which does not meet the specified requirements. This could be because the alloy is overaged under this influence.

The results of fatigue tests are in agreement with each other within the error (and with the initial data), regardless of the number of passes and fluence in the range $1 \cdot 10^{15}$–$1 \cdot 10^{17}$ cm^{-2}, when the radiation is performed under modes 2–4, namely, at lower ion energy E = 20 keV and ion current density j = 400 $\mu A/cm^2$ (narrower collimator, at high travel speed under the beam, which ensured the absence of profile heating and the retention of strength properties). Weller's curves built using the results after testing the initial and irradiated samples are similar. Thus, there is no effect of modes 2–4 on low-cycle fatigue. Since the maximum increase in the cyclic life of the carbon steel as a result of nitrogen and argon ion irradiation was observed at the lowest ion current density (10 $\mu A/cm^2$) in [7], it seems reasonable to irradiate the V95 alloy samples later using lower ion current densities.

4. Conclusions

The effect of Ar^+ ion irradiation on the fatigue resistance of hot-pressed V95 alloy profiles 6 mm thick after quenching and artificial aging (140°C, 16 h) was investigated. Ion irradiation conditions, which enable one to avoid significant heating of a target at E = 20 keV and j = 400 $\mu A/cm^2$, do not affect the fatigue resistance at all used fluences of $F = 1 \cdot 10^{15}$– $1 \cdot 10^{17}$ cm^{-2}.

Thereafter, we are going to carry out electron microscopic studies of the structure and the phase composition of irradiated samples, as well as to search for the optimal irradiation conditions to improve life properties and preserve the specified strength properties of the studied alloy.

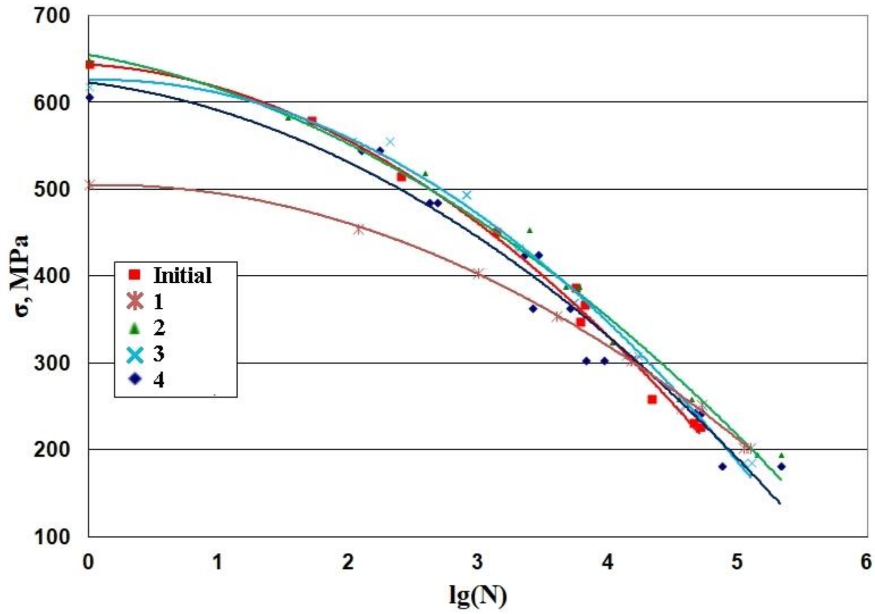

Figure 1. Number of cycles lg(N) as a function of maximum cyclic stress σ for the V95 alloy samples in the initial state after artificial aging and after Ar^{+} ion irradiation in different modes 1–4.

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